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Policy developments for the reduction of climate change impacts by the transportation sector

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ABSTRACT

The transportation sector is one of the most significant sources of anthropogenic greenhouse gas emissions. In order to mitigate climate change, it is important to apply effective and immediate policies to reduce the transportation sector's emissions. This study aims to: (1) define the dimensions of the transportation sector, such as its environmental, economic, social, and political elements, and (2) investigate how they relate to climate change, in order to assess potential mitigation scenarios and policies that could reduce the sector's contribution to climate change. First, sector-related variables were specified using expert opinions and a literature survey. Relationships between the variables and the associated intensity values were then identified using document coding, as well as by gathering expert opinions through a workshop. A fuzzy cognitive map analysis was then conducted to investigate the relationships between the variables and the resulting impacts by the transportation sector on climate change. A scenario analysis was also conducted in order to identify the most effective policies in reducing the impacts of transportation on climate change, at both the local and global levels. For the scenario analysis at the global level, projections by the International Energy Agency were analyzed through the model. The local policy suggestions developed by Turkish authorities were also evaluated using scenario analysis.

1. Introduction

Predictions in the Fifth Assessment Report (AR5) developed by the Intergovernmental Panel on Climate Change (IPCC) generally estimate that a 2.0 °C increase in global average temperature is inevitable. The Copenhagen Accord anticipates that average global temperature change should be constrained to under 2.0 °C, which would necessitate reductions of 40 %–70% of total emissions by 2050, compared to 2010 emissions (IPCC, 2014). The projected warming in the twenty-first century is likely to be between two and ten times as large as the observed warming during the twentieth century (Pittock, 2009).

Statistics given by IPCC (2014) reveal that most of the policies have failed to reduce the growth rate of emissions. The highest decadal anthropogenic greenhouse gas (GHG) increase of human history was actualized in the period between 2000 and 2010 with 1.0 gigatonne CO_2-equivalent (CO_2e) average annual GHG emissions. If GHG emissions continue at current rates, the result would be greater warming and damage to the climate system. The largest source of emissions is from fossil fuel combustion and industrial processes, with an approximate share of 78% (IPCC, 2014). At the Paris climate conference (COP21), 195 countries announced their INDC (Intended Nationally Determined Contributions) values, showing their intended amount of CO_2 emission values in the context of their mitigation capabilities and circumstances. The main objective of COP21 was to set out a worldwide action plan to put the world on track to evade perilous environmental change, by constraining the global temperature increase to well beneath 2 °C. It is evident that delivering the likely outputs of possible action plans is vital. Unfortunately, since the agreement is to start in 2020, the countries have not yet provided action plans including policy options, which would help to build trust and accountability. This study aims to help countries in their efforts to develop effective action plans for this purpose.

Xenias and Whitmarsh (2013) reported that the highest increase in

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GHG emissions has been realized by the transportation sector in recent decades. With 14% of total emissions, ascertaining the current situation of the transportation sector and making scenario analyses by drawing from emission projections is extremely important (IPCC, 2014). Since 1997, transportation has become part of the political agenda of the 38 developed countries who signed the Kyoto protocol. Of these, there are some countries of which the transport-related CO_2 emissions currently appear to be trending downward, since the adoption of the Kyoto Protocol, as in the cases of Germany, France, and Japan (Hayashi et al., 2015). The projections of the International Energy Agency (IEA) reveal that world's primary energy demand is expected to increase by 40% between 2007 and 2030 (IEA, 2013). When emission reductions are compared with the expected increase in energy demands, it can be seen that there is much progress to be made.

The management of GHG emissions in the transportation sector can now be considered as one of the key issues on the national as well as the global level. Various studies on the environmental impacts of energy use (e.g. Sreekanth, 2016; Lu et al., 2016; Taylor et al., 2014) underline the rapid growth of pollutant emissions and reveal that national policy makers are in urgent need of appropriate modeling methodologies that can guide the analysis of the implications of different policies on reducing GHG emissions.

The aim of this study was four-fold; the first objective was to reveal an extensive range of variables that shape the structure of the transportation sector. In the first stage, a survey was conducted to reveal the variables related to GHG emissions in the transportation sector, resulting in a preliminary list of variables. This preliminary list was then sent to five internationally recognized transportation academics working on sustainable transportation, in order to reach a final revised list based on their opinions and suggestions.

The second objective was to analyze, with the participation of ten transportation experts during a workshop, the interrelations between the variables as well as the intensity of these relations (with information on magnitude and direction).

The fuzzy cognitive map (FCM) structure can be used for the evaluation of sector responses resulting from positive or negative changes on a specific component, due to external interventions (policy instruments such as tax, emission limits, carbon pricing, or governmental campaigns in research and development (R&D) incentives, among others). Using the FCM structure, a scenario analysis was carried out in order to assess the impacts of different policy variables on the reduction of GHG emissions.

Although there exist numerous studies that focus on a specific transportation mode (e.g. Liu and Wang, 2017; Han et al., 2017; Tiwari et al., 2016), they do not cover the transportation sector as a whole, but rather focus on a specific sub-transportation mode or class (public transportation, freight or passenger transportation, air transport, road transport, among others). This type of modeling fails to reveal the interactions and the effects resulting from the change (either positive or negative) in other components (modes) of the transportation sector. To overcome this shortcoming, this study investigated the transportation sector as a whole, with a detailed variable description.

In fact, there are studies in literature that considers the transportation sector as a whole such as system dynamics approaches. Shepherd (2014) investigates the utilization of system dynamics approach for the strategic policy analysis of transportation systems and reviewed studies on this research area. The research states that there are studies which analyze transportation planning problems with system dynamic models that offer a whole system approach. These studies analyze the long-term effects of short term policies (see Shepherd, 2014 for details). However, those studies do not take into account uncertainties.

Since the proposed model has an uncertain structure in terms of the vagueness of expert opinions and the fuzzy meanings of the documents analyzed, it allows for the evaluation of "concepts" that cannot be assessed numerically. For example, it would not be possible to include the impact of "behavioral change" into a model without a fuzzy type of evaluation.

The final and the most important aim was to integrate qualitative assessment and rigorous modeling in a way that they complement each other in evaluating the impacts of different strategies on reducing emissions.

Hereby, this study defined the transportation sector in all its aspects, in order to analyze mitigation scenarios and develop policies to reduce the impact of the transportation sector on climate change.

The analysis of transportation sustainability necessitates the investigation of a complex system, with many interrelations among the variables. The policies intended to achieve sustainability may have unintended side-effects and may actually jeopardize the accomplishment of other objectives. Therefore, it is necessary to analyze the issue with a system-wide approach. Transportation systems are closely related to economic, environmental, and social dimensions. Policy makers with the challenge of creating a sustainable transportation sector should take a broad three-pronged approach: physical policies related to physical infrastructure, soft policies aiming to change behavior by informing the actors on the consequences of their choices, and knowledge policies that emphasize the critical role of investment in R&D for a sustainable model.

Planning for a sustainable transportation sector is a complicated task. There is a lack of data, an insufficiency of databases and statistics to guide government, industry and individuals, as well as a lack of the ability to analyze the implications of different policies (such as pricing, taxation, R&D, among others) for demography, energy, socio-economics, emissions and other transport–related variables. For these reasons, research and tools developed to date fall short of developing an agreed-upon strategy to reduce the impact of the transportation sector on climate change (Shiftan et al., 2003). This study overcomes the aforementioned drawbacks by proposing the use of an FCM and scenario analysis that provides a comprehensive basis of quantifying the variables and for the analysis of the effects of a particular policy on reducing the impacts of transportation on climate change from a wider perspective. This is done while taking into account the interrelations between demographic, energy, socio-economic, transportation and emission variables. This paper therefore has important contributions both from the point of view of policy, but also in terms of methodology.

The structure of this paper is as follows: the next section presents a literature survey on the assessment of policies on sustainable transport, FCM, and the use of scenario analysis in transportation planning. The third section highlights the basic steps of the methodology. The fourth section presents the results of the scenario analysis performed and specifies basic policies that should be adopted in order to reduce the GHG emissions of the transportation sector. Finally, conclusions and further suggestions are made.

2. Literature overview

2.1. Assessing policies for sustainable transport

In this study, the main focus of the literature survey is to investigate the research conducted in order to identify the implications of different transportation policies on climate change. The articles evaluated in this study provided the initial list of variables that were chosen to be input in the proposed model. Subsequently, this initial list was revised and enlarged based on expert suggestions. The experts chosen in this study were selected based on their specific areas of expertise. The experts were selected so as to ensure that transportation sector and climate interactions were analyzed from different perspectives (urban planning and economics, economic policy, transportation economics, civil engineering, distribution, and logistics). Therefore, although they are all transportation experts, each concentrates on a different sub-topic, which helped to have a rich and homogeneously-distributed set of parameters and thus a resulting model that was able to represent their interactions.

Studies usually define a system of indicators under some main aspects (or pillars) and evaluate predetermined policy suggestions on the system. Studies mostly differ on how they define the system, goals, application area, and, of course, the methods or techniques employed, as presented in Table 1.

As can be seen from the literature, although sustainability in transportation and its impacts on climate change have been widely studied, the research conducted so far has had a number of limitations:

- Applied on specific locations, for example: Schfer et al. (2009) focused on the United States; Hensher (2008a,b) studied the Sydney Metropolitan area and the Central Coast; Holden et al. (2013) proposed an appraisal strategy to evaluate the effects of policy instruments on the transportation sector of Sydney, Yang et al. (2009) and Verma et al. (2015) presented case studies in California and Bangalore city respectively; Hickman et al. (2010) developed a model for London; Liimatainen et al. (2015) made forecasts for Finland and Sweden. Hickman et al. (2010) developed a transportation and carbon simulation model for London in order to evaluate the impacts of different potential policy packages to achieve headline CO_2-emission reduction targets.
- Concentrated on only one solution dimension, for example: technological changes in Schfer et al. (2009); Kwan and Hashim (2016),

Table 1
Literature review on transportation policy evaluations.

Article	Goal	TC	Z	Methodology	Focus
Bojkovic et al., 2010	Evaluate transportation sector performance w.r.t. sustainability	ST	R	ELECTRE method	System as a whole
Bueno, 2002	Investigate numerous scenario options to decrease energy utilization in various transportation areas	LT	L	Decomposition	System as a whole
Goulden et al., 2014	Evaluate the drivers of transportation demand considering growth assumptions	LT	L	Decomposition	System as a whole
Greenblatt, 2015	Evaluate of policy choices	LT	L	Simulation	System as a whole
Gudmundsson and Sørensen, 2013	Reveal the indicators that have an effect on strategic policy making (potential impact of different types of information and assessment on legislative issues, organization, or administration)	MT	LR	ASSESS study	System as a whole
Hensher, 2008a	Evaluate the impacts of transportation and non-transportation policy instruments on urban travel behavior		L	Simulation	System as a whole
Hensher, 2008b	Reveal the influence of emission-mitigation policies that refer to passenger transport	ST	L	Simulation	Passenger transport
Hickman and Banister, 2007	Perform a back-casting study for the transportation sector and a policy evaluation based on "Policy Packages"	MT	L	Quantitative modeling	System as a whole
Hickman et al., 2010	Evaluate the impacts of different potential policy packages to achieve headline CO_2-emission reduction targets		L	Simulation	System as a whole
Holden et al., 2013	Present an evaluation strategy to shield long-term natural sustainability, while fulfilling essential transportation needs	MT	L	Sustainable Transportation Space Model	Passenger transport
Holden et al., 2013	Define sustainable passenger transportation with its dimensions and related indicators			IPAT-ASI-SMART Models	Passenger transport
Kwan and Hashim, 2016	Investigate studies focused on environmental benefits, especially on reduced air pollution from urban public transport			Literature Review	Passenger transport
Liimatainen et al., 2015	Evaluate CO_2 mitigation for road freight transport	MT	L	Delphi	Road freight transport
Mattila and Antikainen, 2011	Explore sustainable future through quantitative modeling on long-distance freight transport	LT	R	Quantitative modeling	Long-distance freight transport
Rothengatter, 2010	Investigate the effects of the integration of aviation in an emission-trading system on climate change	LT	R	Discussion	Aviation
Shiau and Peng, 2012	Develop an indicator system for measuring mode-based transportation sustainability at the local level	ST	L	AHP	System as a whole
Shiftan et al., 2003	Explore the future development of the Tel-Aviv Metropolitan Area	MT	L	DELPHI	Public transport
Stanley et al., 2011	Evaluate GHG mitigation scenarios for road transport	MT	L	Forecast	Road transport
Tsamboulas et al., 2007	Evaluate the impacts of a policy on modal shift	MT	R	GIS-based Macro_Scan	System as a whole
Turton, 2008	Explore long-term (to 2100) interactions between energy and transportation sectors and the broader economy, on a global 11-region scale	LT	R	Energy and Climate Policy and Scenario Evaluation (ECLIPSE) model	System as a whole
Ubbels et al., 2003	Study the development of the international transportation sector based on four globalization scenarios	MT-LT	LRG	Decomposition	System as a whole
Verma et al., 2015	Assess the impacts of various transportation policies and projects based on environmental, economic, and social variability	ST	L	Evaluation with the Composite Sustainability Index (CSI) weighted by means of AHP	Road transport
Xenias and Whitmarsh, 2013	Perform a sector-wide assessment of innovative and behavioral alternatives to reduce GHG emissions		L	A mixed-methods approach comprising both qualitative and quantitative elements	System as a whole
Yang et al., 2009	Policy evaluation	LT	L	Scenario Analysis	System as a whole
Yai et al., 2015	Evaluate transportation-sector technology w.r.t. GHG emissions	LT	L	TIMES	System as a whole

TC: Time coverage (S: Short-term: M: Mid-term, L: Long-term) – Z: Zone coverage (L: Local, R: Regional, G: Global).

threshold values of specified indicators in Holden et al. (2013); modal shifts in Xenias and Whitmarsh (2013) and Tsamboulas et al. (2007).

- Took into account limited modes of transport, for example: Stanley et al. (2011) and Liimatainen et al. (2015) dealt with roads; Xenias and Whitmarsh (2013), Holden et al. (2013), and Malayath and Verma (2013) focused on passenger transportation; Schfer et al. (2009) discussed automobiles and aircraft. Stanley et al. (2011) investigated ways by which road-transportation emission values can be reduced in order to lower GHG emissions to the suggested levels in Australia. Hensher (2008a) developed a simulation program called TRESIS (Transportation, and Environment Strategy Impact Simulator) as a policy admonitory device to assess the effects of transportation and non-transportation policy instruments on urban travel behavior
- Considered limited dimensions, for example: Hickman et al. (2010) explored options for reducing emissions, but did not consider socio-economic aspects of the problem; Xenias and Whitmarsh (2013) did not perform a sector-wide evaluation that highlights transportation sustainability measured from a macro perspective, taking into account the interrelations of alternatives with the technological, socio-economic and demographic variable categories. Elvik and Ramjerdi (2014) performed a comparative analysis of the effects of policy instruments in promoting only environmentally sustainable transportation in terms of their elasticities. Ewing et al. (2008) analyzed the impacts of compact development on reducing the distances traveled and hence on lowering carbon emissions.

To summarize, besides the location-specific nature of these approaches, most of literature studies do not take into account the impact of those policies on broader socio-economic, demographic systems. To the best of our knowledge, no study covered such a comprehensive list of parameters that allows for the analysis of the interactions within the transportation sector (with all its socio-economic, demographic, and technology-related variables), and of the overall impact of these interactions in reducing the climate-change impacts of transportation.

Before adopting or implementing any policy, it is vital for policy makers to be conscious of its impacts from an extensive point of view, using an integrated approach (Malayath and Verma, 2013).

Verma et al. (2015) developed a Composite Sustainability Index, which includes the three pillars of sustainability: environmental, social, and economic. They expressed these pillars based on various indicators. However, their research only provided a framework, which still remains to be applied in order to test the impact of different transportation policies. As a result, they argued against reducing sustainability to a single composite index.

As suggested by Santos et al. (2010) and Gudmundsson and Sorensen (2013), although such an integrated approach is needed, no research has been presented to date with such a broad perspective. Santos et al. (2010) analyzed the impacts of policies categorized as being physical, soft, and knowledge-based. They advocated for the development of an integrated transportation policy (covering environment, health, economy, and society), with regards to the different modes of transportation. They also underlined that such an integration will be necessary for all social groups and relevant institutions and policy makers.

Additionally, many of the studies focusing on specific components of the transportation sector are based on rigorous modeling, but they do not account for the qualitative impacts of different variables. In fact, the latter is another important approach for setting policy. An important contribution of this work is in how the two approaches complement each other.

2.2. Why use an FCM?

The initial literature review in Section 2.1 demonstrated the difficulty of performing a direct evaluation of the CO_2 emissions of the transportation sector and climate change. This has been attributed to the multi-dimensional structure of the variables involved and their complex interrelations. One approach that could lead to a network model, offering a more comprehensive analysis, is FCM. FCM can explain the state of demography, energy, socio-economic, transportation, emission, and policy variables over the long term, i.e. how they are affected by other variables, the playing out of various scenarios, and the ongoing discussion following from the results obtained. FCM allows the modeler to consider a complex structured problem by running simulations based on specific scenarios to monitor the system response resulting from the changes in the variables.

Human belief systems or mental modes can be represented and analyzed in a network structure that can capture the causality among related variables (Surer et al., 2015). In this field, perceiving, contextualizing, simplifying, and making sense of complex issues may be described as cognition, while providing graphical descriptions with which individuals view a particular domain may be defined as mapping. A cognitive map (CM) can be viewed as a representation of how a problem is being considered (Axelrod, 1976; Eden, 1988, 1992; Tolman, 1948).

In a CM, nodes represent variables, while arrows (edges) represent directional influences that belong to causal effects/dependencies between variables (Srinivas and Shekar, 1997). The directional influences can be valued with one of the trivalent values [-1, 0, 1], where '-1' indicates a negative causality, '0' no causality, and '+1' a positive causality. The directional effect can get the values of [-1,0,1] where "0" denotes no relation between two variables, and "1" stands for the existence of causal relation: "+" for positive and "-" for negative. A variable at the tail of an arrow is taken to affect or influence the variable at the arrowhead. If an increase (or decrease) in the value of tail variable leads to an increase (or decrease) in the value of a head variable, then there is a positive causality. A negative causality is just the contrary: an increase (or decrease) in the value of the head variable leads to a decrease (or increase) in the value of a tail variable.

As expert judgments are used to construct a CM, a subjective environment carrying uncertainty exists, for which FCM is an appropriate approach. Kosko created a FCM in 1986 as a soft computing tool based on fuzzy logic and neural network methodologies (Papakostas et al., 2008). Studies on FCM have since been carried out in various fields of science, such as psychology, management, and planning.

Kosko (1986) states that CMs are not sufficient as the trivalent values [-1, 0, 1] of CM are a restriction for a fuzzy causality environment (Surer et al., 2015). The usage of phrases such as little, weak, partially, usually, a lot, strong, among others, are very convenient for decision analysts in summarizing the judgments of experts. Therefore, on a FCM, nodes and arrows still exist as they do on a CM for the representation of variables and effects among variables respectively, but additionally to CMs, the strengths of impacts are also assessed. For this purpose, arcs in the FCM are valued between -1 and 1 allowing degrees of influence to be represented. Hence, its graphical illustration appears as a graph consisting of nodes and weighted arcs. Fig. 1 exhibits such an illustrative FCM.

When a variable C_i affects another variable C_j (i.e. C_j is the arrowhead and C_i is the tail of the arrow), W_{ij} indicating the causality between C_i and C_j will be either positive $(0 < W_{ij} \leq 1)$ or negative $(-1 \leq W_{ij} < 0)$. If there is no causality, then there will be no arrow between nodes $(W_{ij} = 0)$.

Yaman and Polat (2008) suggest that FCMs are the combination of CMs, quantitative values, and time. An FCM also allows modelers to perform scenario analysis to provide insights about the effects of the change on the value of a variable. The change is updated through an iterative process that occurs periodically (Tsadiras, 2007).

During the first step of the process, an $n \times n$ adjacency (influence) matrix is constructed with the number of variables being n. For instance, the FCM given in Fig. 1 corresponds to the adjacency (valency) matrix presented in Table 2.

In the second step, a $1xn$ state vector (denoted by S) is generated based on A_i, the degree of activation of the variables. A_i^0, the activation

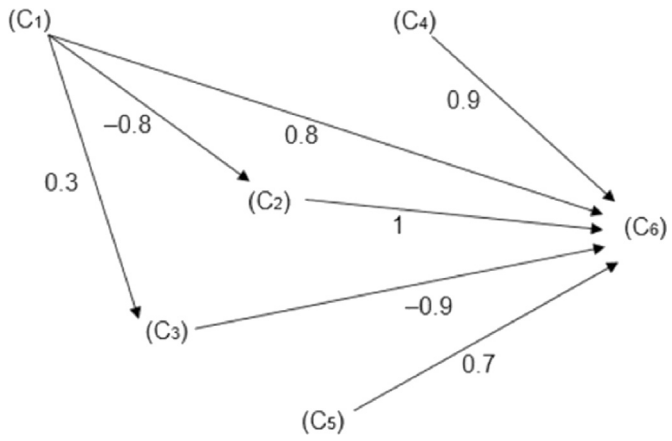

Fig. 1. An FCM.

level of variables in the initial step, are derived from a fuzzification phase (the procedure of generating fuzzy input values from initial crisp input values) in order to construct an initial state vector S^0 (Peña et al., 2007). The values that belong to the variables are influenced not only by the interconnected variables and the associated weights of causality degrees, but also by their former values. An iterative equation, as given below, is used to produce updated values of variables:

$$A_i^{(k)} = f\left(A_i^{(k-1)} + \sum_{j\neq i} A_j^{(k-1)} w_{ji}\right) \quad (1)$$

where; $A_i^{(k)}$ is the activation level of variable C_i at the kth step, $A_j^{(k-1)}$ is the activation level of the interconnected variable C_j at the k-1st step, W_{ji} is the weight of causality degree between variables C_j to C_i, and f is an activation function utilized to decrease the activation level into a normalized range (Papageorgiou et al., 2006).

Four of the commonly preferred activation functions (bivalent, trivalent, logistic and sigmoid) are presented below respectively (Tsadiras, 2007):

$$f(x) = \begin{cases} 0, & x \leq 0 \\ 1, & x > 0 \end{cases} \quad (2)$$

$$f(x) = \begin{cases} -1, & x \leq -0.5 \\ 0, & -0.5 < x < 0.5 \\ 1, & x \geq 0.5 \end{cases} \quad (3)$$

$$f(x) = \frac{1}{1+e^{-cx}} \quad (4)$$

$$f(x) = tanh(x) \quad (5)$$

In function (2) the activation level of each neuron becomes either 0 or 1. Binary functions lack the ability of representing a decrease of the concept. The use of this function results in each concept being either activated or not activated. Function (3) creates three different states, whereas in functions (4) and (5) the activation level takes any value in the interval [-1,1]. However, trivalent functions cannot represent the degree of an increase or a decrease in a concept while sigmoid functions do.

For the third step, having determined the type of activation function and created an initial state vector for a given scenario, a simulation is run to investigate the effects of a change on the system at hand. There exist two termination options for a simulation analysis, including setting the limit on the number of iterations and the condition of values (belonging to the variables in the constructed model) reaching a stable form.

To illustrate the simulation analysis, the FCM given at Fig. 1 is analyzed. Suppose a hypothetical scenario that indicates an increase in the 3rd variable. Using Eq. (5), the simulation results given in Table 3 are obtained. As can be seen in the table, the state values of the variables converge at iteration 11. The results can be interpreted as follows:

- an increase in C_3 will increase the level of C_1;
- an increase in C_3 will decrease the level of C_2 and C_6;
- in the long run, C_3 has no effect on C_4 and C_5;

2.3. Why use scenario analysis?

As mentioned in Section 2.2, FCM is able to reveal the interactions of the systems that make up a complex network. FCM not only elucidates the network, but is also a successful tool in gaining insight into the system's response and future states under various scenarios, by use of the simulation analysis (Murungweni et al., 2011; Kontogianni et al., 2012).

Although deterministic forecasting models are widely used to determine the influence of logistics on the improvement of trade or economic development, the basic drawbacks of such models are that they typically provide a single prediction and they do not include qualitative system changes (Tietje, 2005). In fact, particularly for long-term planning, back-casting, scenario analysis, and foresight techniques are considered to be the kind of information that transportation decision makers will require in highly uncertain future conditions (Schuckmann et al., 2012; Wangel, 2011; Mattila and Antikainen, 2011; Potter, 2007).

The literature survey conducted underlines that scenarios are not forecasts but they give an internally consistent view of what the future might be. Scenario analysis has emerged as a useful tool for long-term planning when the future is perceived to be subject to a high degree of uncertainty and complexity (Tietje, 2005). In fact, the climate change and transportation sector interaction is a very complex issue having different stakeholders, interacting with government objectives, institutions, and socio-economic objectives as well as technological objectives. Therefore, it is not possible to obtain reliable forecasting for such a complex system. For this reason, scenario analysis was selected as a suitable method of projection in this study. FCMs and scenarios are an effective means for providing a holistic view of the climate change issue.

Table 2
The adjacency matrix of the FCM in Fig. 1.

	C_1	C_2	C_3	C_4	C_5	C_6
C_1	0	−0.8	0.3	0	0	0.8
C_2	0	0	0	0	0	1
C_3	0	0	0	0	0	−0.9
C_4	0	0	0	0	0	0.9
C_5	0	0	0	0	0	0.7
C_6	0	0	0	0	0	0

Table 3
Simulation results of a hypothetical scenario.

Iteration	C1	C2	C3	C4	C5	C6
0	0	0	1	0	0	0
1	0.7616	0.0000	0.7616	0	0	−0.7163
2	0.9093	−0.5436	0.7574	0	0	−0.6598
3	0.9311	−0.8541	0.7740	0	0	−0.8203
4	0.9360	−0.9215	0.7831	0	0	−0.9255
5	0.9378	−0.9316	0.7872	0	0	−0.9471
6	0.9385	−0.9331	0.7889	0	0	−0.9505
7	0.9387	−0.9334	0.7896	0	0	−0.9511
8	0.9389	−0.9334	0.7899	0	0	−0.9512
9	0.9389	−0.9334	0.7901	0	0	−0.9512
10	0.9389	−0.9335	0.7901	0	0	−0.9512
11	0.9389	−0.9335	0.7901	0	0	−0.9512

Identifying interrelations among the variables and taking into account the perspectives of different experts, the impacts of different policies on the reduction of GHG emissions can be assessed. As a case study, ten strategies for sustainable transportation proposed by the IEA and the Ministry of Transport, Maritime Affairs and Communications of Turkey (UHDB) were analyzed and their efficacy in reducing the impacts of transportation on climate change were investigated.

3. Methodology

The main stages of the methodology are given in Fig. 2.

3.1. Identification of variables

The first stage involves the identification of the CM nodes, in other words, the variables that define the system. This task can be based on existing literature and expert opinion. For the current study, a combined method was used. Initially, a preliminary list of variables was prepared based on relevant literature (Stanley et al., 2011; Yang et al., 2009; Plambeck, 2012; Verma et al., 2015; Hickman and Banister, 2014; Gilbert and Perl, 2010; Hickman et al., 2010; Cobb and Thompson, 2012; Reisi et al., 2014; Limanond et al., 2011; Pittock, 2009; Owen and Hanley, 2004). These studies were selected by searching through the literature using the keywords "climate" and "transportation" on web of science and sciencedirect.com. All the related studies were analyzed using the document-coding method explained by Wrightson (1976). The basic idea is to code each causal assertion in terms of its three components: cause, connector, and effect. The causes and effects were declared as the variables in all climate change and transportation related causal assertions.

Afterwards, the list of variables was revised based on the opinions of experts in the scientific committee of the WCTRS, who specifically study climate change-transportation interactions. These experts revised the variable list and decided which certain concepts had to be eliminated from or included in the concept list. This final list of 74 variables, related to the impacts of transportation on climate change, was organized into demography, energy, socio-economy, transportation, emission, and policy categories (see Tables 4 and 5).

3.2. Identification of relations

The second step of the methodology is the derivation of a CM. According to the literature, CMs can be built based on document coding, questionnaire surveys and individual interviews (Axelrod, 1976). In this study, a hybrid methodology was used again in order to identify the relations between the variables. Initially, the causal assertions coded in the identification of the variables were used to reveal the relations. For example, consider the following hypothetical statement: "emissions resulting from human activities are increasing the atmospheric concentrations of GHGs substantially". "Human activities" is regarded as the cause; "emissions" is regarded as the effect; and the connector is "+" since there is a positive impact of the cause variable on the effect variable. Moreover, "emissions" is also the cause for "GHG concentrations". The connector is again "+", since an increase in the emissions results in an increase in the atmospheric concentrations of GHGs.

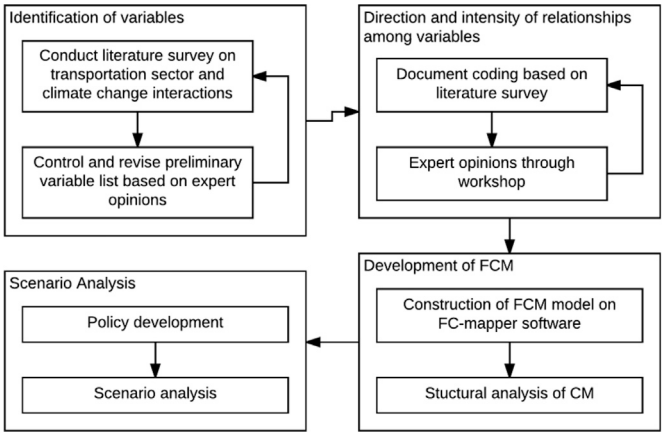
Identification of variables
Conduct literature survey on transportation sector and climate change interactions
Control and revise preliminary variable list based on expert opinions
Direction and intensity of relationships among variables
Document coding based on literature survey
Expert opinions through workshop
Development of FCM
Construction of FCM model on FC-mapper software
Stuctural analysis of CM
Scenario Analysis
Policy development
Scenario analysis

Fig. 2. Basic steps of the methodology.

Subsequently, a workshop was held to determine the final map based on expert opinions. For this purpose, ten internationally recognized transportation experts were invited to the workshop to produce the final list of variables. The CM produced via document coding was shown to them and they were asked to revise the relations between the variables according to their opinions and to also provide the intensity of these relations. The final map obtained is given in Appendix 1. In order to show the strength of the relations the adjacency matrix can be seen in Appendix 2.

By means of the constructed CM, the effects of a change in the value of a specific factor can be traced. As an example, in Fig. 3, the magnitude and the direction of the relationships of variables with "public transportation" are presented. The figure shows that a change in the level of public transportation has a strong positive effect on urban mobility and a negative impact on the levels of road congestion.

3.3. Evaluation of the revised FCM

Once the final CM is derived, a number of analyses can be conducted to obtain relations between the variables. Initially the map has to be converted to an *nxn* adjacency matrix A, where n represents the number of variables in the CM, and the values of the direct causal relationships from concept variable *i* to concept variable *j*, serve as its entries.

One of the basic analyses used for CM is to calculate the "density" of the map, which corresponds to the ratio between the number of connections and the number of all possible connections between all variables (Özesmi and Özesmi, 2004). A higher ratio indicates a densely-connected map and a higher level of cognitive complexity. Moreover, a higher density indicates the potential of available management policies. Similarly, a CM of which the complexity level is low is expected to have an insufficient recommendation, since this simplicity is a sign of vision narrowness about the work that is being conducted. The density ratio of our CM was found to be 0.22 (74 variables, 1214 relations), which is relatively high, as compared to other studies presented in the literature (Vasslides and Jensen, 2016; Papageorgiou et al., 2006; Kontogianni et al., 2012; Özesmi and Özesmi, 2004).

The second common analysis is a 'centrality analysis'. The centrality score can be calculated simply by adding the "in-degree" (the sum of the absolute values that belong to the elements of column *i* in the adjacency matrix) to the "out-degree" (the sum of the absolute values of the elements of row *i* in the adjacency matrix) for each variable (Eden et al., 1992). Those nodes whose scores are highest are assumed to be the most cognitively central. Centrality represents a variable's contribution to the overall subject since it shows the connection between the variable and the rest of the map. In other words, centrality is an indicator that presents how connected the variable is to other variables and what the cumulative strength of these connections is (Papageorgiou et al., 2006; Kontogianni et al., 2012). According to this, Public transportation [D5] is the most central concept of our CM (68 links, 33 in-degree 35 out-degree value). This is followed by Car kilometers traveled [D28] with 67 links (32 in-degree 35 out-degree) and Congestion Index [D21] with 65 links (29 in-degree 35 out-degree). Since the focus of our study was to analyze the relations between the dimensions of the transportation sector to climate change, these three variables being the most central variables of the CM is an expected result.

Another analysis categorizes the variables into three groups, transmitter variables, receiver variables, and ordinary variables, to provide information about the behavior of the variables (Özesmi and Özesmi,

Table 4
List of variables used in the study.

A. Demography			
A.1	Population change	A.3	Development growth
A.2	Demographic change	A.4	Urbanization rate
B. Energy			
B.1	Energy use per person	B.3	Energy cost
B.2	Energy intensity	B.4	Fuel consumption
C. Socio-economic development			
C.1	Access to modern technology	C.8	Employment rate
C.2	Information and number of trained people	C.9	Total household consumption of transportation
C.3	Road congestion and traffic accidents	C.10	Number of households that cannot afford a car
C.4	Gross Domestic Product (GDP)	C.11	Income elasticity
C.5	Contribution of transportation to GDP— Gross Value Added (GVA)	C.12	Short-term price elasticity for trans. demand
C.6	Motorization	C.13	Long-term price elasticity for trans. demand
C.7	Household income	C.14	Travel demand
D. Transportation factors			
D.1	The load factor (payload)	D.19	Accident risk in rail transportation
D.2	Passenger car–electric and hydrogen	D.20	Accident risk in air transportation
D.3	Vehicle fuel efficiency	D.21	Congestion Index
D.4	Modal shift opportunities	D.22	Passenger transportation volume
D.5	Public transportation	D.23	Freight transportation volume
D.6	Quality of public transportation	D.24	Per capita road length
D.7	Road quality	D.25	Total length of reserved transit
D.8	Passenger car–diesel	D.26	Quality of dedicated cycling roads
D.9	Passenger car–gasoline	D.27	Length of footpaths
D.10	Passenger car–LPG	D.28	Car kilometers traveled
D.11	Light Duty Vehicle (LDV) – diesel	D.29	Share of urban trips performed by walking
D.12	Heavy Goods Vehicle (HGV) – diesel	D.30	Share of urban trips performed by cycling
D.13	Road share of inland freight transport	D.31	Car occupancy rate
D.14	Car share of inland passenger transportation	D.32	Average trip length
D.15	Share of non-motorized individual transportation	D.33	Quality of dedicated walking paths
D.16	Trip time	D.34	Supply chain optimization
D.17	Accident risk in road transport	D.35	Utilization
D.18	Accident risk in sea transport	D.36	Vehicle qualifications
E. Emissions			
E.1	Emissions per person	E.7	External costs
E.2	CO_2e emissions (road transport)	E.8	Carbon intensity–diesel
E.3	CO_2e emissions (sea transport)	E.9	Carbon intensity–gasoline
E.4	CO_2e emissions (rail transport)	E.10	Carbon intensity– Liquefied Petroleum Gas (LPG)
E.5	CO_2e emissions (air transport)	E.11	Carbon intensity–kerosene
E.6	Noise	E.12	Indirect emission
F. Politics			
F.1	Pricing	F.9	Household automobile type choice
F.2	Taxation	F.10	Investment to each transportation mode
F.3	Research and innovation	F.11	Operational cost
F.4	Efficiency standards and flanking measures	F.12	Behavioral change program
F.5	Internal market	F.13	Encouragement of vehicles using alt. fuel options
F.6	Infrastructure	F.14	External markets
F.7	Transportation planning	F.15	Emission trading
F.8	Subsidies and taxes	F.16	Clustering in production
G. Climate change			

2004). A variable that has a positive out-degree and a zero in-degree is called a "transmitter", whereas "receiver" variables have a zero out-degree accompanied by positive in-degree. In our map, only one variable can be considered a receiver variable, that is Climate Change [G], while Population Change [A1] is the only transmitter variable. The rest are ordinary variables. This is due to the heavy relationships among all the variables other than these two. The receiver variable, Climate Change in our study, is defined as a goal variable, in the sense that it is influenced by other variables in the system but does not influence other variables. Therefore, throughout the analysis, the value of the receiver variable is the one to be studied, if various levels of changes in different variables of the system are taking place. On the other hand, the transmitter variable, Population Change in our study, can be defined as the "driver" variable, since a change in a transmitter variable can affect all the system including the receiver variables.

4. Scenario analysis and policy implications

The wide scope of this study aims not only to reveal the interrelationships among the variables identified for the transportation sector, but also to deduce the intensity of the effects resulting from changes in factor values. To this end, a FCM, combining the variables gathered from academic journals, official international documents, and expert opinions was used. The scenario analysis section is twofold, validating the utility of the model in evaluating global and local scenarios by examining two different cases. Firstly, the implications of global IEA scenarios were analyzed by use of the model. Secondly, as a case study, Turkey was selected and the local policy suggestions developed by Turkish authorities were evaluated. Statistics reveal that the Turkish primary energy consumption has increased at a 5.1% annual growth rate over the past 50 years. Therefore, Turkey is required to mitigate its GHG emissions by the Montreal Protocol using the Revised IPCC Guidelines, IPCC Good Practice Guidance, and Uncertainty Management in National Greenhouse Gas Inventories (TurkStat, 2015).

In order to conduct the scenario analysis, variables that are increased or decreased are initially identify based on scenario specifications. Then, a simulation analysis is applied to the FCM, as defined in Section 2.2. Finally, the long-term changes in the other variables are reported.

Table 5
Variable definitions by global perspective scenario.

Scenario	Variables (change)
G1	D.3 Vehicle fuel efficiency (+1)
G2	F.3 Research and innovation (+1)
	F.3.1 Research and development in technology (+1)
G3	F.2.1 Carbon taxation (+1)
	F.4.1.3 Environmental standards (+1)
	F.13 Encouragement of alternative fuel options (+1)
G4	D.3 Vehicle fuel efficiency (+1)
	F.3 Research and innovation (+1)
	F.3.1 Research and development in technology (+1)
	F.2.1 Carbon taxation (+1)
	F.4.1.3 Environmental standards (+1)
	F.13 Encouragement of alternative fuel options (+1)

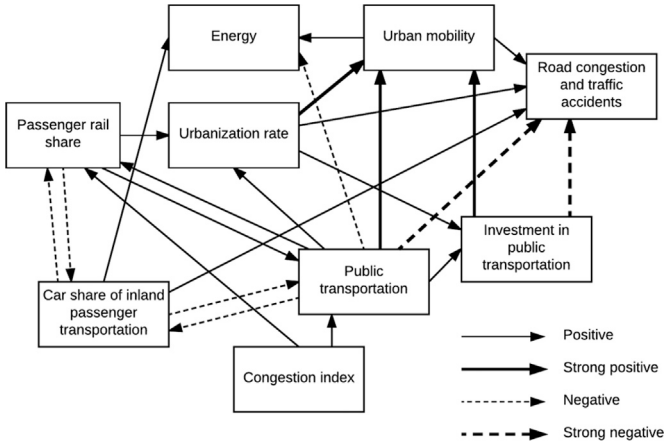

Fig. 3. Part of the CM focusing on public transportation.

4.1. Global perspective

To find alternative solutions and to predict the potential damages resulting from emissions, the IEA is required to develop alternative scenarios and strategies that advise policy makers and enable the Group of Eight Leaders to find a way of avoiding the threat of climate change (IEA, 2005). In this section, utilizing the constructed FCM as a policy-evaluation tool, the ACT Scenario (the aim of which is to depict energy efficiency and de-carbonization activity gains), introduced by the IEA under "The Energy Technology Perspectives Scenario Analysis", is evaluated (See Table 3 for the definitions of scenarios and Figs. 4–6 for the related results) (see Fig. 7).

As can be seen from Table 4, four different scenarios were investigated. The G1 scenario analyses the effects of the increase in vehicle fuel efficiency. The main objective of this investigation is to study the impacts of technological shifts in the transportation sector, one of which may occur in fuel efficiency. The G2 scenario aims to explore the effects of R&D efforts in the transportation sector. For this reason, the levels of "Research and innovation" as well as "Research and development in technology" variables are increased in this scenario. From another point of view, the G3 scenario aims to investigate the effects of low-carbon energy alternatives. Lastly, in the G4 scenario, all actions in scenarios G1, G2, and G3 are assumed to be performed simultaneously.

4.1.1. Scenario G1

In this scenario, only the improvement of vehicle fuel efficiency in each transportation mode is evaluated, in order to reveal the impacts of a technological shift in the transportation sector. It is anticipated that an increase in vehicle efficiency alone would have the lowest positive effect in carbon emission mitigation, as compared to other global actions defined in the IEA ACT scenario. As can be seen in Fig. 4, the first finding is a decrease (−0.0057) in public transportation to a considerable extent. Additionally, it is predicted that, due to a substantial increase in efficiency, the use of privately owned vehicles, running not only on fossil fuels but also on alternative energy sources, would increase (passenger car-electric and hydrogen: 0.0085; diesel: 0.0032; gasoline: 0.0032; LPG: 0.0031).

4.1.2. Scenario G2

In accordance with the aim of GHG-emission mitigation, this scenario investigated the effects of R&D incentives and the implementation of R&D activities on technology (defined in the IEA ACT scenario). As can be seen from Fig. 5, vehicle design and innovation (0.0115), supply chain optimization activities (0.0086), and truck utilization (0.0068) values are expected to increase as a benefit of R&D activities. Alternative fuel vehicles are anticipated to become more preferable for consumers (passenger car-electric and hydrogen: 0.0188). Energy use per person (−0,0028) and consumption of conventional fuels like diesel (−0.008), gasoline (−0.008), and LPG (−0.0078) show a downward tendency.

4.1.3. Scenario G3

IEA (2008) states that the CO_2 emissions resulting from urban transportation are anticipated to increase at a slow rate for the period of 2010–2050, while simultaneously intercity and local transportation are

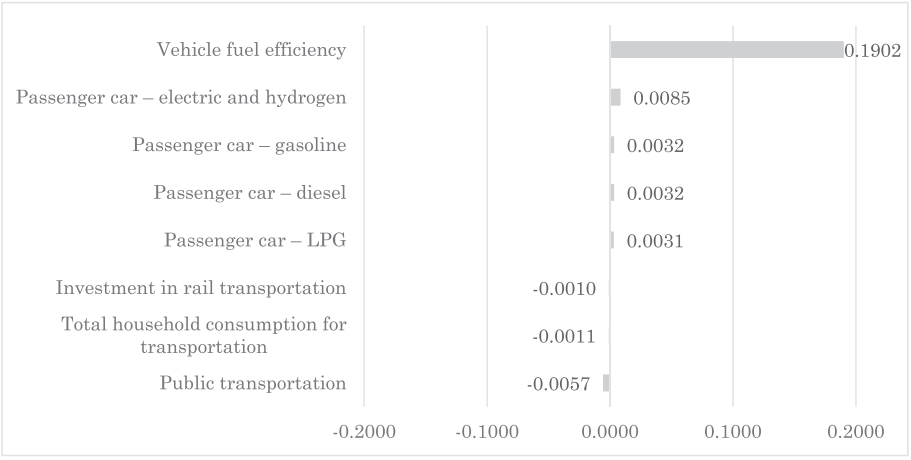

Fig. 4. Results of scenario G1.

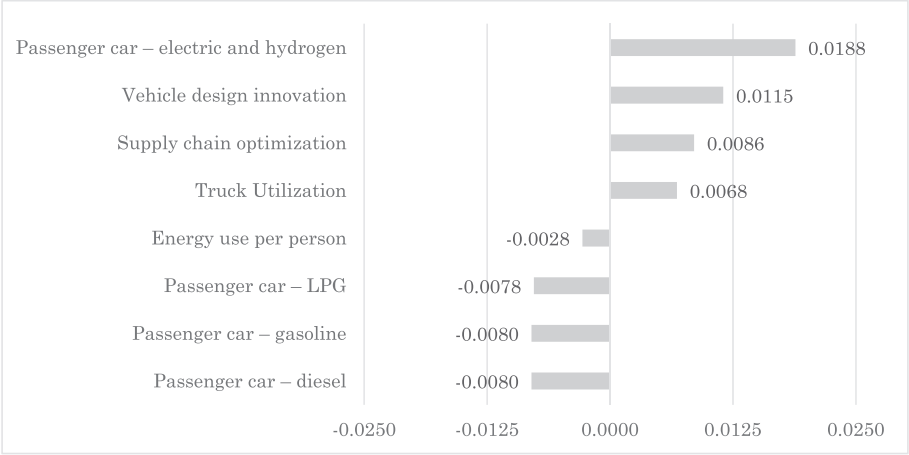

Fig. 5. Results of scenario G2.

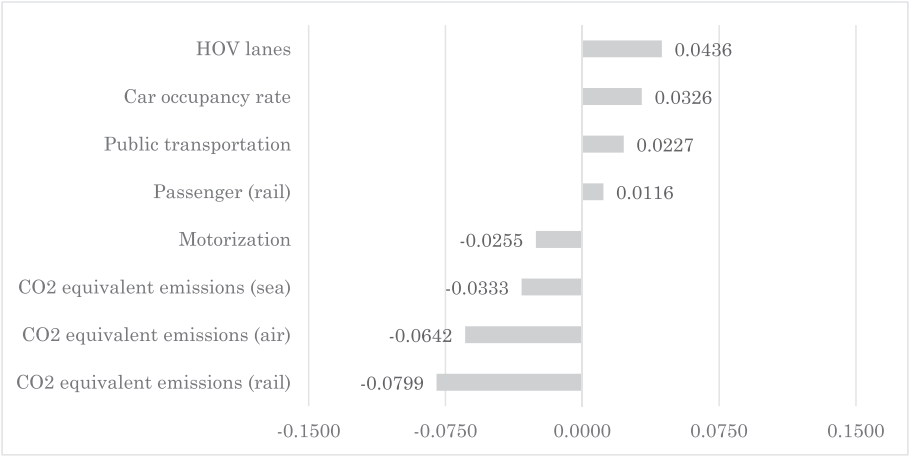

Fig. 6. Results of scenario G3.

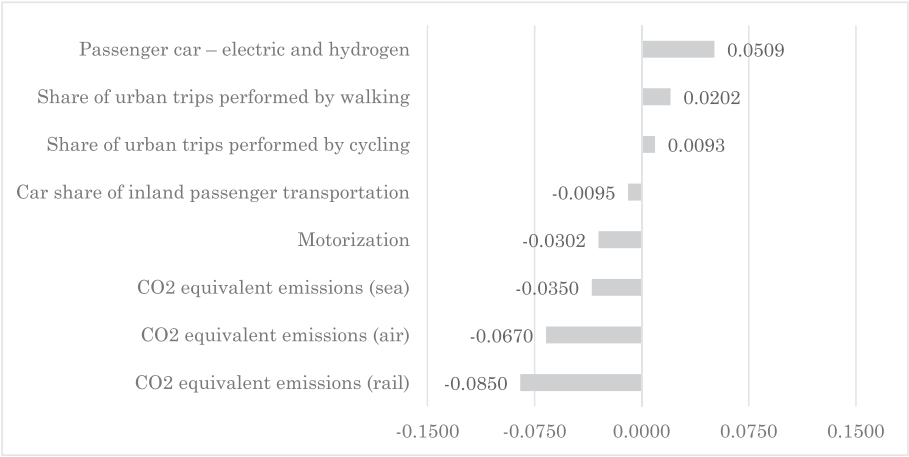

Fig. 7. Results of scenario G4 – combined scenarios.

expected to grow dramatically (about 70% by 2050). OECD (Organisation for Economic Co-operation and Development) countries are also expected to show considerable growth of their own in these areas. Therefore, creating a stable policy framework that boosts the consumption of low-carbon energy alternatives is considered as one of the key factors in the ACT scenario. That is why in this scenario the effects of Carbon taxation, Environmental standards, and Encouragement of alternative fuel options variables are analyzed. As can be seen from

Fig. 6, the results show that dramatic decreases in CO_2 emissions occur in all kinds of transportation modes (CO_2e emissions from sea transport: −0.0333; air transport: −0.0642; rail transport: −0.0799). Motorization also decreases (−0.0255) in conjunction with the decreases in both passenger and freight transportation. The results also reveal that these policies can be expected to boost public transportation (0.0227), especially rail transportation (passenger rail share: 0.0116). Optimization and planning actions are also affected positively; ride-sharing programs and High Occupancy Vehicle (HOV) lane usage (0.0436) are promoted; and as an inevitable result, the occupancy rate (0.0326) is relatively high.

4.1.4. Scenario G4 - combined scenarios

In conjunction with the aforementioned scenarios, an additional model run was performed to gather information on system response under the assumption that all actions are introduced simultaneously. In this situation, car share of inland passenger transportation (−0.0095) and motorization rate (−0.0302) are anticipated to decrease. Likewise, due to the reduction in total household consumption for transportation and total travel demand, CO_2e emissions for each transportation mode will be reduced (CO_2e emissions from sea transport: −0.035; air transport: −0.067; rail transport: −0.085). Moreover, alternative transportation options (passenger car–electric and hydrogen (0.0509), share of urban trips performed by cycling (0.0093), and walking (0.0202)) will be favored. This shows that an explicit political strategy is necessary to diminish the total emission values resulting from all transportation modes, as well as development of technology offering transportation activities at low emission rates.

4.2. Local perspective: a case study from Turkey

In order to validate the use of the model, not only globally but also nationally, Turkey was selected as a case study. The latest OECD performance reviews for Turkey (OECD, 2008) revealed that the rapid increase in road freight and passenger traffic are the major causes leading to air pollution. The same reviews claim that taxes on motor fuels and vehicles have not brought about significant changes (See Table 6 for definitions of the scenarios and Figs. 8–13 for related results).

The impacts of the strategies released for 2035 by UHDB were also investigated. This analysis assessed the benefits of the various actions and required investments related to GHG emissions caused by transportation in Turkey. This should enable policy makers to observe the effects of different policies on the transportation sector with regard to reducing its climate change impacts.

As can be seen from Table 6, six different scenarios were investigated. The L1 scenario analyses the effects of a decrease in road transportation. For this reason, the levels of "Freight transportation volume by road", "Road share of inland freight transport" and "Car share of inland passenger transportation" variables have been reduced in L1. The L2 scenario tries to explore the effects of a potential improvement of road quality. From another point of view, the L3 scenario aims to investigate the effects of using HOV lanes (restricted highway lanes reserved for the use of vehicles with a specified number of passengers to support carpooling) and toll charges. In the L4 scenario, the number of vehicles that use alternative fuel options is increased in order to see the impacts of a potential encouragement of non-conventional vehicles. The L5 scenario aims to investigate the results of R&D activities that are conducted in the fuel-consumption field. Lastly, the effects of an increase in the level of investment in rail transportation are analyzed in the L6 scenario.

Table 6
Variable definitions by scenario from a local perspective.

Scenario	Variables (change)
L1	D.23.1 Freight transportation volume (tons carried) by road (−1) D.13 Road share of inland freight transportation (−1) D.14 Car share of inland passenger transportation (−1)
L2	D.7 Road quality (+1)
L3	F.6.2 HOV lanes (+1) F.1.5 Toll charges (+1)
L4	F.13 Encouragement of vehicles using alternative fuel options (+1)
L5	F.3.1.4 Research and Development on fuel consumption (+1)
L6	F.10.2 Investment in rail transportation (+1)

4.2.1. Scenario L1

The first scenario was selected among the 40 primary goals for 2035 set by UHDB. Its primary aim is the transferal of road transportation journeys above 500 km to other transportation modes. Actions to fulfil this objective would result in a decrease in "Freight road share", "Road proportion of inland freight transportation", and "Car proportion of inland freight transportation". The results are shown in Fig. 8. As expected, "motorization" is affected negatively (−0.013) as vehicle-km values decline. Consequently, for freight transportation a shift to rail (0.0909), and for passenger transportation a shift to air (0.0542) and rail (0.0149) are expected. Another interesting finding is the negative effects on the usage of renewable fuel vehicles (−0.0307), when the goal is to reduce road usage.

4.2.2. Scenario L2

The impact of a government policy to increase the quality of roads is found to cause a decrease in public transportation (−0.0157), resulting in an increase in privately owned vehicles using not only fossil fuels but also alternative energy sources (passenger car-electric and hydrogen: 0.0218, diesel: 0.009; gasoline: 0.009; LPG: 0.0088). Motorization is also increased (0.0022), as expected due to the increase in road quality.

4.2.3. Scenario L3

HOV lanes and toll charges are also two of the primary goals for 2035 set by UHDB. The effects of increases in these variables are investigated together in scenario L3. In the results presented in Fig. 10, an increase in car sharing is observed (higher car occupancy) (0.0213). Toll charges incentivize public transportation (0.0071) and rail transportation (0.0067). Accordingly, motorization would be negatively affected (−0.0217) and there would be a significant decrease in the congestion index (−0.0034).

4.2.4. Scenario L4

The encouragement of vehicles using alternative fuel options is mainly based on incentivization through tax exemptions and other advantages. The effects of a shift from conventional vehicles using fossil fuels to vehicles using sustainable energy sources is investigated. According to the results in Fig. 11, as expected, renewable consumption (0.0203) and electric and hydrogen passenger car usage (0.0080) increase. As the consumption of traditional fuel types decreases, emission values per person (CO_2e emissions from sea transport: −0.0039; air transport: −0.0071; rail transport: −0.0089) will decrease. It is important to underline that the increase in renewable consumption is more significant than the decrease in CO_2 emissions. Therefore, the encouragement of vehicles using alternative fuel options is not expected to decrease CO_2 emissions dramatically.

4.2.5. Scenario L5

One of the primary goals is to increase R&D in the road transportation sector. In this scenario, the effects of R&D incentives are investigated. Results in Fig. 12 show that the only adverse impact is observed on "motorization" (−0.0104). Positive effects are observed primarily on electric- and hydrogen-powered passenger cars (0.0113). At a lower level, vehicles using alternative fuels will also be affected positively (0.0009). Additionally, slight improvements are expected to be observed in supply chain optimization (0.0082), average truck utilization (0.0065), and fuel efficiency (0.0012).

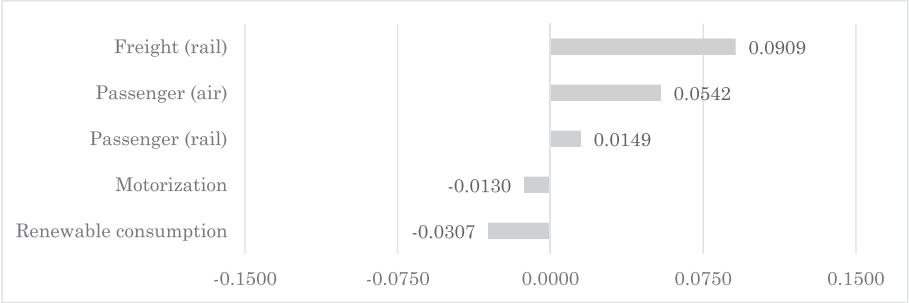

Fig. 8. Results of scenario L1.

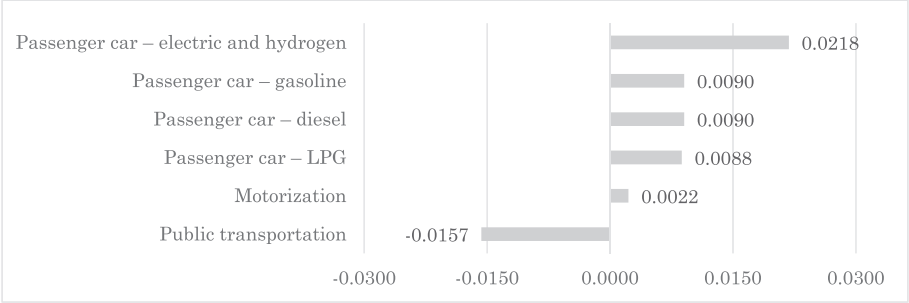

Fig. 9. Results of scenario L2.

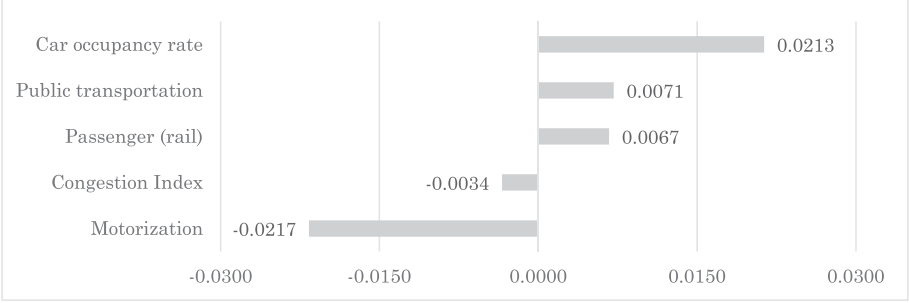

Fig. 10. Results of scenario L3.

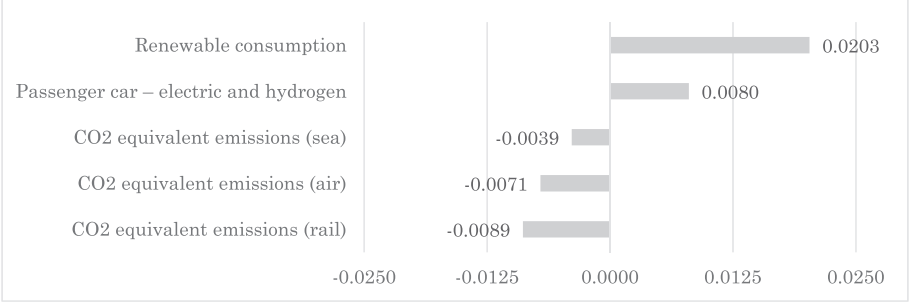

Fig. 11. Results of scenario L4.

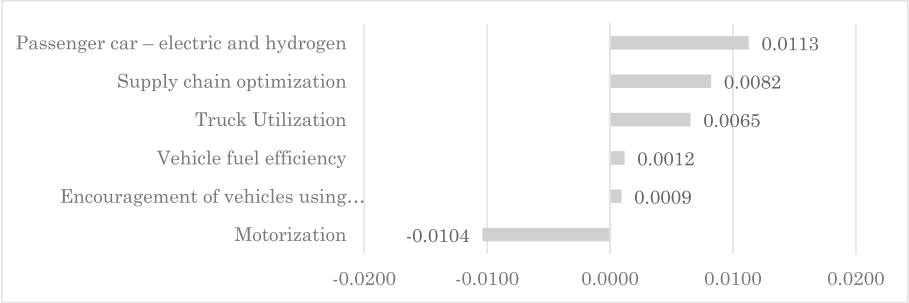

Fig. 12. Results of scenario L5.

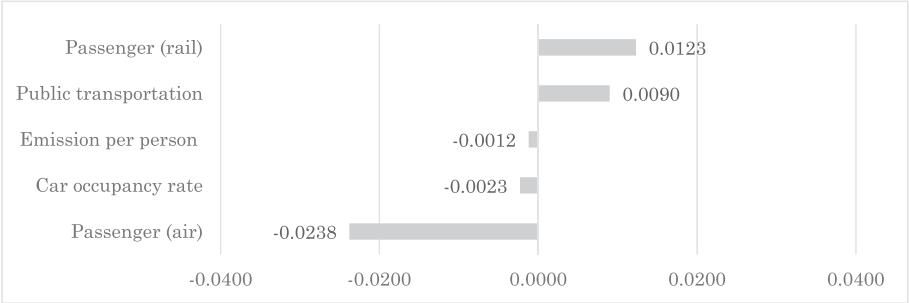

Fig. 13. Results of scenario L6.

4.2.6. Scenario L6

One of the goals of UDHB is to make further investments in rail transportation. The projects related to this goal are "increasing the total network length to 31,000 km by building 6000 km of new rails" and "connecting 15 cities with populations greater than 60 million with high-speed trains". Results in Fig. 13 show that the increase in investment in rail transport results in the decrease of GHG emissions (−0.0012). The most significant decrease is observed in the passenger air share variable (−0.0238). The high-speed train investments will attract passengers not only from the roads (car occupancy rate: −0.0023) but also airlines. The kerosene (75.2 kg CO_2·mmBTU^{-1}) used as aircraft fuel is much more harmful than motor gasoline (70.2 kg CO_2·mmBTU). For this reason, encouraging passengers to use rail transportation rather than air transportation is more environmentally beneficial than encouraging a shift from road to rail. Since high-speed train investments aim to meet the demand for intercity transport, they will substitute a substantial proportion of air travel and have a strong positive effect on GHG emissions from the transportation sector.

4.3. Policy implications

The global and local scenarios examined in this study have important policy implications. Analysis of the implications of IEA ACT scenarios shows that an improvement in vehicle efficiency alone does not have a major effect on the reduction of carbon emissions. On the other hand, R&D incentives and policy actions including carbon taxation, encouragement of alternative fuel options, and environmental standards result in a marked reduction of climate impacts. In fact, toll charges (which can be considered as a type of congestion charge) and HOV lines have already been implemented in some OECD countries to mitigate GHG emissions (OECD, 2010). Toll charges are a way of charging drivers for the usage of specific roads and can be continuously in place or only valid for a pre-defined period during peak-time traffic congestion. For example, the congestion charge had an immediate impact on London's transport, reducing the number of cars, vans, and lorries. Similarly, Singapore introduced a road pricing scheme in 1975 called the Area License Scheme (ALS) to tackle increasing congestion (Santos et al., 2010). Toll charges and HOV lanes are critical policy tools offering road pricing options promoting driver awareness of the connection between vehicle use and its effects on the wider society and the environment (Monsalve, 2013). By imposing such regulations, demand reduction due to an increase in the relative price is the goal, and this in turn promotes the use of public transportation. Liu et al. (2010) also dealt with congestion pricing and formed a system dynamics model covering peoples' perception affecting their mode choice and the flow of revenues for reinvestment of toll revenues into the bus and metro systems. In our model, this policy had the strongest effect on climate change by shaping transportation mode selection and diminishing passenger-car usage demand, car share of inland passenger transport, and motorization.

The current increasing travel demand naturally leads to increased fuel demand, since petroleum fuels are a fundamental component of today's transportation infrastructure. However, there exist significant problems associated with their use, such as oil depletion and environmental concerns, which make an urgent case for the popularization of alternative fuel options. Governmental campaigns include behavioral change programs aimed at increasing awareness, investment in the production of modified motor types, research and development actions, investment in biofuel production (including the possibility of exportation), constructing electric-vehicle charging facilities, imposing taxes and offering monetary incentives that make alternative fuels competitive, among others; briefly stated, this includes any actions that increase the uptake and scope of alternative fuel vehicles. Han and Hayashi (2008) revealed that the increases in fuel taxes besides development of railway network and reduced emphasis on highway extensions will have a positive effect for the reduction in gas emissions.

Additionally, advanced transportation technologies have the potential to promote the transition towards a sustainable transportation sector. Hybrid electric and fuel-cell technologies, along with hydrogen fuels and biomass, are considered to be promising candidates for a transition to sustainability (Turton, 2006). For example, major automakers in Japan

are in competition for the development of hybrid vehicles and fuel cell vehicles.

When the overall effects on climate change are investigated, it appears that scenario L3 has an evident potential for emission mitigation. Compared to other action plans (investment projects that require considerable capital and time), enacting legislation on toll charges and HOV lanes is the most effective course of action with regards to time and money. Looking at the fact that taking action as soon as possible is of supreme importance, Scenario L3 should be prioritized.

Scenario L4 also has a significant positive influence on climate change. When demand switch is made easier, the market penetration of environment-friendly fuel consumption in the transportation sector is promoted, and government promotion of clean energy reduces petroleum fuel use, resulting in a noticeable decrease in CO_2e emissions.

Besides alternative energy uses (scenario L4), R&D for technology improvement (scenario L5) is also an important measure. Advanced transportation technologies that consumed environment-friendly fuels have the potential to reduce urban air pollution.

More specifically, a modal shift and investment in railway transportation (scenario L1 and scenario L6) are necessary strategies to be considered for the case of Turkey. In particular, shifting journeys greater than 500 km to other transportation modes should become a policy aim. Actions to fulfil this goal will result in a decrease in "Freight road share" and an increase in "Road and car share of inland freight transport". Regarding emissions, rail is one step ahead of road transportation due to its lower levels of CO_2 emissions (half as much emissions as road transport) (Santos et al., 2010). Once again, there should be a focus on investments in rail infrastructure in order to have an effect on intermodal operations.

5. Conclusions and further suggestions

Despite of the fact that some studies have been conducted aiming to assess the components of the transportation sector, they either focus on specific portions of the sector rather than observing the system as a whole or does not consider uncertainties. To fill this gap, an extensive range of components was investigated in order to shape the structure of transportation sector.

Moreover, the transportation sector was presented in a CM as a whole, with a detailed description of said components in the structure. Some studies evaluated the effects of transportation sector components by specifying a weight within the sector in a general manner. In contrast, in this study, the effects of changes in the components are presented in a more detailed manner. Rather than an aggregate effect, the changes in other components are obtained with the information of volume and direction. Additionally, the model is constructed with a fuzzy-nature. The model is capable of evaluating components that cannot be precisely measured (such as the effects of behavioral-change programs on the transportation sector).

In this study, an FCM was developed to include all the related variables for a sustainable transportation sector. For this purpose, a hybrid approach based on literature survey and expert opinion was used. Subsequently, the relative intensity of the relations between the variables was specified based both on document coding and expert opinion gathered from a workshop. Finally, a scenario analysis was conducted, with policies suggested for both the local and global level. For the global policy evaluation, the ACT scenario defined by the IEA was examined. As an example of a local analysis, Turkey was selected as a case study and the implications of the policies suggested by UDHB were analyzed.

Most importantly, this work demonstrated how qualitative assessment of the impacts of different variables and rigorous modeling can complement each other in developing strategies to reduce the impacts of the transportation sector on climate change.

The results of the global scenario analysis reveal that the improvement of vehicle fuel efficiency, results in a decrease in public transportation and an increase in privately owned vehicles that use alternative energy sources. An increase in R&D activities leads to an increase in vehicle design and innovation, which will also result in the use of alternative-fuel vehicles as well as a downward trend in energy use and consumption of conventional fuels. This improvement will also result in a supply-chain optimization of the efficiency of various activities, as well as increased truck utilization. The development of environmental policies like carbon taxation and the encouragement of alternative fuel options, results in a dramatic decrease in CO_2 emissions in all kinds of transportation modes. Motorization and both passenger and freight transportation also decrease due to these regulations.

From a localized perspective, the results of the scenario analysis conducted for Turkey reveal that the decrease in freight transportation by road leads to a downward trend in motorization. As expected, freight transportation by rail and air increase. The improvement of road quality results in an increase in privately-owned vehicles, using not only fossil fuels but also alternative energy sources. The increase in HOV lanes and toll charges cause a decrease in motorization as well as in the congestion index. An encouragement of vehicles using alternative fuel options results in a reduction in emission values per person and consequently a decrease in emissions in the transportation sector, as expected. The increase in R&D activities leads to an improvement in electric- and hydrogen-powered passenger cars.

The use of the developed FCM for the analysis of the impacts of policy proposals suggested by UDHB is expected to provide significant near-term insights for present Turkish policy makers. However, in its current state, the scenarios are based on many current trends and institutional drivers and do not take into account future uncertainties. As a further study, the research could be extended to take into account possible future trends and uncertainties, and to analyze the impact of different policies, not only for one country, but for a broader economy on a regional and global scale. The level of emissions is a product of a comprehensive system, including socio-cultural, demographic, technologic and economic changes. Therefore, the impacts of different policies could be analyzed with the use of predefined scenarios of the above-mentioned drivers.

The integration of scenario planning and multi-criteria decision analysis (MCDA) offers the possibility of specifying the strategic options that should be focused on, by informing within and across scenario comparisons of options (Goodwin and Wright, 2009). Therefore, as a further approach, an MCDA methodology could be applied to identify the most valuable strategies to focus on.

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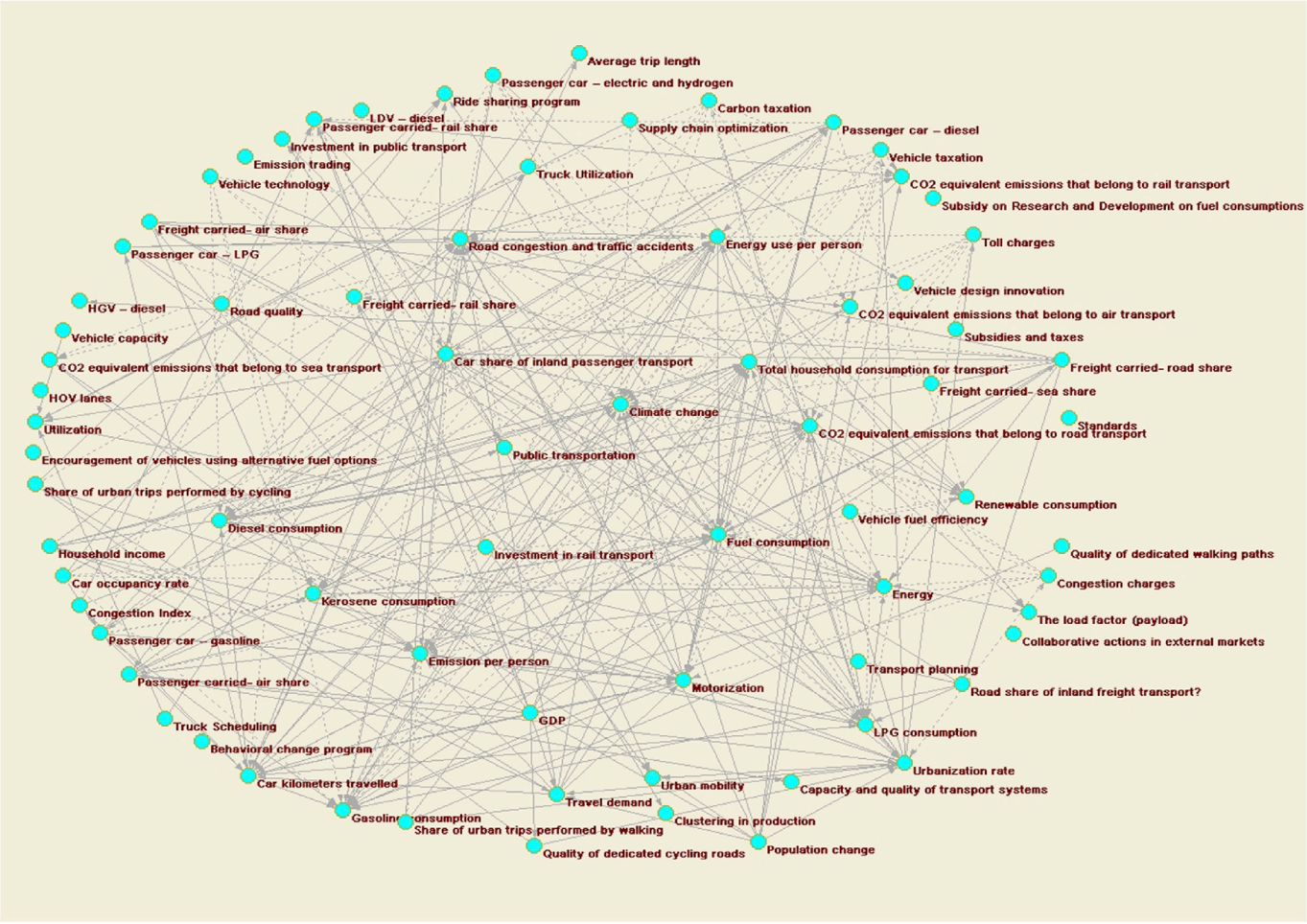
Appendix A. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.tranpol.2017.09.008

Appendix 1



The final cognitive map derived.

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